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THE p-TYPE-GaAs(1-x)P(x) n-TYPE-GaAs HETEROJUNCTION SOLAR CELLS

A. G. Cheban, V. V. Negreskul, P. T. Oush,
L. V. Gorchak, G. I. Unguryanu, V. G. Smirnov

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ABSTRACT. Measured dark current-voltage characteristics, light current-voltage characteristics under load, and spectral response curves are given for photosensitive elements prepared by liquid epitaxial growth of p-type $GaAs_{1-x}P_x$ on an n-type GaAs substrate. Due to the absence of a conditioning surface layer, 30% of the radiation incident on the working surface is reflected, yielding an efficiency of 6 to 7%. Recommendations are given for improvement in this area. A72-30225

The development of methods for the epitaxial growth of thin layers of dif- /30* ferent semiconductor crystals has made it possible to create heterostructures in the $GaAs_{1-x}P_x$-GaAs system, interest in which has made it possible to build efficient photoelectric converters with many definite advantages over silicon photoconverters [1 - 5].

Solid solutions of $GaAs_{1-x}P_x$ provide a forbidden zone of optimum width and an increase in the percentage of utilization of solar energy. $GaAs_{1-x}P_x$-GaAs heterojunction photocells can operate at elevated temperatures, and with light concentrators, without significant changes in energy parameters (I_{sc}, U_{oc}, efficiency).

This paper contains the results of the investigations made of the volt-ampere, load, and spectral characteristics of heterostructures made using the liquid epitaxial growth method and solid solutions of $GaAs_{1-x}P_x$ on a GaAs substrate. The purpose of these investigations was to develop the feasibility of using p-$GaAs_{1-x}P_x$-n-GaAs heterojunctions as photoconverters.

Single-crystal layers of solid solutions of $GaAs_{1-x}P_x$ were obtained by epitaxial growth from the liquid phase on a substrate of gallium arsenide [6-7]. The substrate used was n-type GaAs with μ = 2500-3500 cm^2/V-sec and an electron

* Numbers in the margin indicate pagination in the foreign text.

concentration of $7 \cdot 10^{16}$ to $4 \cdot 10^{17}$ cm^{-3} at ambient temperature. The oriented crystals of n-GaAs in plane (111) were covered with a gallium solution containing dissolved gallium phosphide and an alloy, zinc, in pure hydrogen. The growing single-crystal films of p-$GaAs_{1-x}P_x$ took place between 760 and 910°C, ensuring coincidence of the position of the heterojunction and the substrate-layer boundary, and avoiding the formation of a homojunction in the gallium arsenide because of diffusion of the zinc from the growing epitaxial layer. The epitaxial layers usually were 20-30 microns thick.

The composition and homogeneity of the solid solutions were monitored by X-raying and by measuring reflection spectra [8]. The GaP content in the solid solutions was 10 mole %. The concentration of current carriers in the p-layer of $GaAs_{1-x}P_x$ was $\sim 2 \cdot 10^{18} - 10^{19}$ cm^{-3}. Ohmic contacts were made after chemical processing by fusing indium in hydrogen.

Dark volt-ampere characteristic curves for the photocells can be described /31 by the equation $I = I_0 \left[\exp\left(\frac{eU}{\beta kT}\right) - 1\right]$. Figure 1 shows the ln I = f(U) relationships in the conducting direction for voltages $kT/e < U < U'_{read}$ for specimens obtained at a growing temperature of 830°C and different cooling rates. As will be seen, the ln I_{st} dependence on the voltage for the p-$GaAs_{1-x}P_x$-n-GaAs heterojunctions can be characterized by one linear section, the slope of which is equal to $\beta = 1.8$-2.0, and $I_0 = 10^{-10} A/cm^2$, thus agreeing satisfactorily with the theory [9]; that is, the injection mechanism of the flow of current, with recombination of the carriers in the space charge layer, can be observed. The shape of the dark volt-ampere curve, and the parameters β and I_0, depend on the conditions under which the solution of gallium saturated with phosphorus and arsenic is cooled, and there is some optimum cooling condition leading to a curve matching that in the theory [9]. There are no sections with small β in the case of high displacement voltages in the conducting direction, and this can be associated with the high series resistances of the instruments.

An increase in the cooling rate should lead to retention of the dissolved admixtures in the bound state; that is, to lesser β and I_0 values, but in this case the probability of the formation of structural defects introduced during the epitaxial growth of the heterojunctions at the substrate-layer interface increases. These factors have a significant effect on the shape of the load curves for p-$GaAs_{1-x}P_x$-n-GaAs solar cells in which the junction depth of the p-n /32 structure is 1 to 4 μk and is commensurate with the depth of penetration of surface defects. Figure 2 shows the load curves measured during solar illumination of 720 W/m^2 of two p-$GaAs_{1-x}P_x$-n-GaAs solar cells, obtained for cooling rates of 10°C/min and 15°C/min. The short-circuited current is decreased at higher cooling rates. In the case of sudden cooling of the saturated gallium solution there evidently is the possibility of an increase in the concentration of defects acting on the parameters determining the magnitude of the photoelectric current, on the life time of the minority carriers, for example.

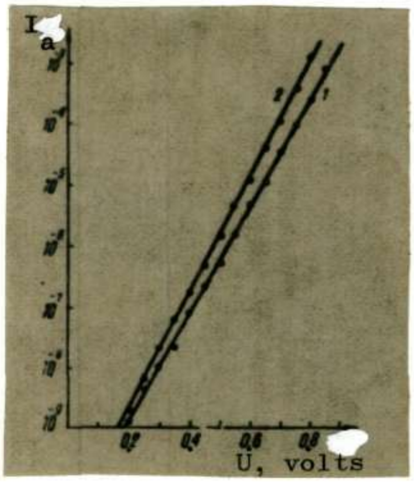

Figure 1. Straight branch of the dark volt-ampere curve for heterophotocells, p-$GaAs_{1-x}P_x$-n-GaAs at 300°K, obtained for different cooling rates.
Cooling rate, °C/min : 1 - 10; 2 - 15.

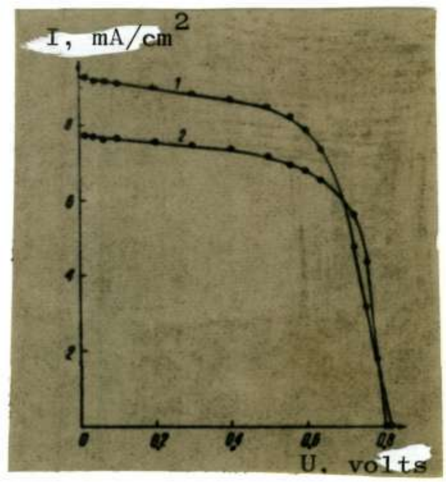

Figure 2. Load curves for photocells p-$GaAs_{1-x}P_x$-n-GaAs (x = 0.1) for solar illumination. Cooling rate °C/min :
1 - 10; 2 - 15.

On the other hand, flaws can occur at the heterojunction interface because of differences in the permanent crystal lattices of GaAs and $GaAs_{1-x}P_x$. Since the compositions of the solid solutions are very nearly GaAs it is probable that the difference in the permanent lattices plays a minor role in the formation of recombination centers. What takes place when cooling rates are lower is a more uniform distribution of impurities in the growing p-layer, a reduction in the effective concentration of recombination centers, and this increases the life time of the minority carriers and, correspondingly, the light current.

The principal parameters of photocells, determined from their characteristic curves, are (1) open circuit voltage, U_{oc} = 0.81-0.83 V, (2) short-circuited current, I_{sc} = 7.5-10 mA/cm^2, (3) efficiency, η = 6-7 percent, (4) filling factor, γ = 0.6-0.7.

Analysis of the efficiency must include the fact that some 30 percent of radiation incident at the working surface of the cell can be reflected because the specimen has no interfacial transmission layer. Hence, efficiency will increase after the application of an interfacial transmission coating and after certain production processes are improved. Figure 3 shows the spectral distribution of the coefficient of collection of pairs of these junctions converted to one incident photon, with consideration given to the reflection factor in terms of photon energy. We see that the area of photosensitivity of a heterophotocell is quite broad and is bounded by the energy interval 1.4-3.2 eV. Two maxima are well defined on the spectral sensitivity curves, one a long-wave one at 1.45 eV very nearly the width of the GaAs forbidden zone, and a broad short-wave one at 2.2-2.4 eV. The coefficient of collection maximum at 1.45 eV is the result of the absorption of light in the volume and separation of the photocarriers at the heterojunction interface. Expansion of the spectral distribution of the coefficient of collection into the short-wave region of the spectrum, and the rise in $\alpha(h\nu)$, obviously depends on the increase in the electron diffusion length because of the presence of a drawn-out electric field attributable to the variable width of the p-region forbidden zone. However, determination of the composition of the growing layer shows no great deviation from the alloy as /33
calculated and was of the order of 10 mole % GaP in the solid solution. On the other hand, excitation of the nonequilibrium carriers took place in different sections of the Brillouin zone. This indicates that minority nonequilibrium carriers excited in a different extremum of the conductance zone can, for the most part, reach equilibrium in the zone in less than the life time ($<10^{-9}$ sec). It is probable that the broad maximum in the photosensitivity of heterojunctions in the 2.2-2.5 eV region is attributable to the indirect junctions at point X in the conductance zone [10]. The drop in photosensitivity in the energy region above 2.5 eV can be caused by the increase in the role played by surface recombination with increase in the light absorption factor.

The chief merit of the heterophotocells obtained is that the solar cells based on them can be used at elevated temperatures, above 200°C, and provide for a possible increase in the percentage of use of the energy in the solar spectrum. Further improvement in the technology of obtaining better quality epitaxial layers of solid solutions of $GaAs_{1-x}P_x$, and the creation of heterojunctions, will permit making a significant increase in the efficiency of photocells.

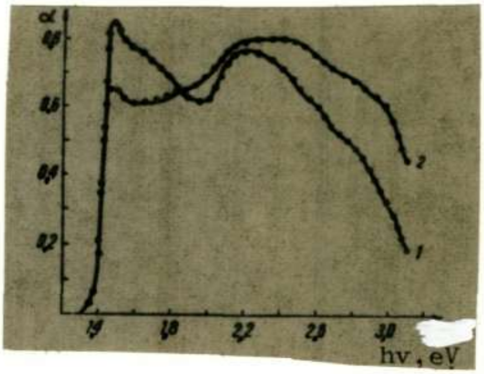

Figure 3. Spectral distribution of coefficient of collection when T = 300°K. Cooling rate, °C/min: 1 - 10; 2 - 15.

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Kishinev

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